RECENT EARTHQUAKES IN WESTERN OHIO[1]

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INTRODUCTION

On March 2 (9:48 A. M.) and again on March 9 (12:45 A. M.), 1937, western Ohio and surrounding states were shaken by earthquakes of such strength as to be generally felt throughout Ohio and detected in the adjacent states of Kentucky, Indiana, Michigan, western Pennsylvania, and West Virginia. Seismographs at Xavier University at Cincinnati and John Carroll University at Cleveland recorded shocks, lasting from 2 to 3 minutes, on both of these dates.

The purpose of this paper is to describe the method employed to locate the epicenter by a non-instrument type of study and to briefly outline the pertinent geologic conditions in the vicinity of the epicenter. After each earthquake a survey of western Ohio was made dealing with the intensities of the shocks in the different regions as revealed by disturbances of objects on the earth's surface. These disturbances were in the form of property damage, movement of objects in buildings, displacement of monuments in cemeteries, and numerous other miscellaneous phenomena. Careful analysis of the displacement of objects showed that the direction of movement of the earthquake waves at specific points could be determined. Since the two earthquakes had a common epicenter and differed only in intensity, they generally will be discussed together throughout this paper.

INTENSITY OF THE EARTHQUAKES

Brief mention should be made regarding the intensities of the earthquakes before discussing the epicenter of these quakes. Since the epicenter is that surface area where the earthquake waves are felt first and where the property damage is the great-

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est it naturally follows that a study of the relative damaging effects of an earthquake will help to delimit the epicenter. In order to have a uniform method of evaluating earthquake intensities seismologists have established certain intensity scales in which varying degrees of property damage and human reactions are grouped under specific intensity numbers. The Rossi-Forel scale, given below, is one such scale.

ROSSI-FOREL SCALE

I. *Microseismic shock*: Recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. *Extremely feeble shock*: Recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. *Very feeble shock*: Felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. *Feeble shock*: Felt by persons in motion; disturbance of movable objects, doors, windows; cracking of ceiling.

V. *Shock of moderate intensity*: Felt generally by everyone; disturbance of furniture, beds, etc., ringing of bells.

VI. *Fairly strong shock*: General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. *Strong shock*: Overthrow of movable objects, fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. *Very strong shock*: Fall of chimneys, cracks in the walls of buildings.

IX. *Extremely strong shock*: Partial or total destruction of some buildings.

X. *Shock of extreme intensity*: Great disaster, ruins, disturbances of the strata, fissures in the ground, rock-falls from mountains.

The particular value of such a scale is that it enables one to submit questionnaires to residents in different parts of the affected areas and on the basis of their answers plot isoseismic maps showing the intensities of the earthquake in specific regions. The intensity will be greatest, that is highest number, in the vicinity of the epicenter and will decrease outward from this area. Such a map was drawn for the earthquakes in western Ohio and is shown in Figure 1.

The second earthquake, March 9, was of much greater intensity than the first one of March 2. This statement is readily apparent to those who experienced both shocks and is further verified by the greater property damage caused by, and

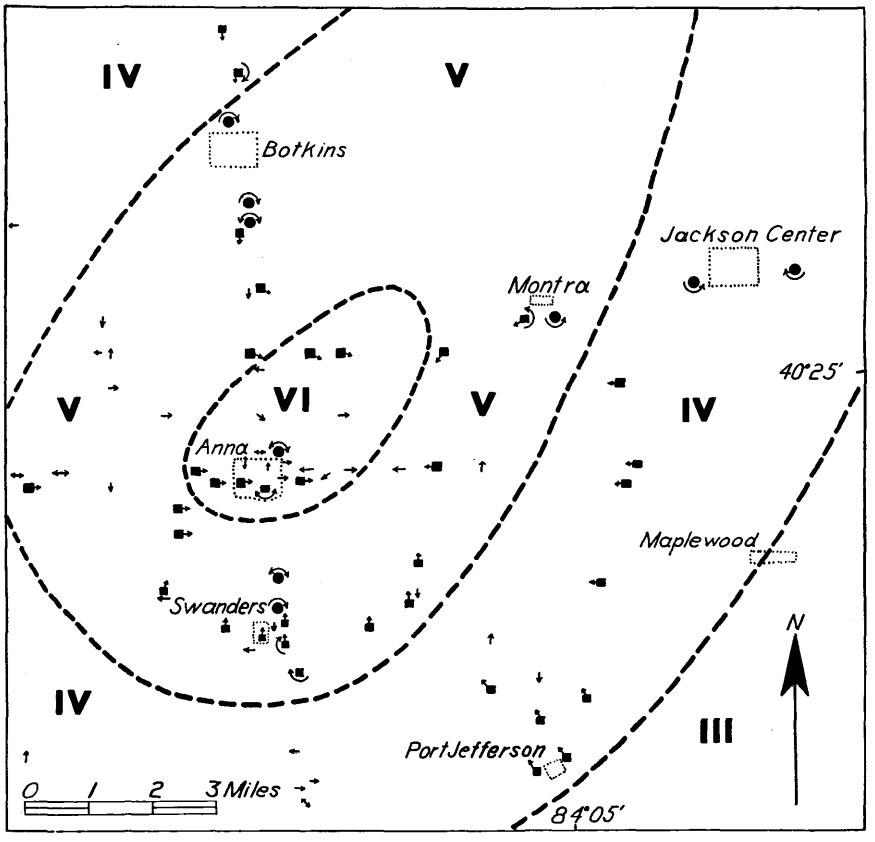


Figure 1. Isoseismic map of the epicenter and vicinity for the earthquake of March, 9, 1937. Roman numerals refer to Rossi-Forel Scale intensity numbers, the area marked VI being the epicenter. Arrows indicate direction of movement of non-fixed objects in buildings. Black squares represent chimneys, the attached arrows showing the direction they fell or the direction they leaned after the earthquake. Black circles, cemeteries, the arrows showing the direction of rotation of sectional monuments; if an arrow is present on both ends of the line it indicates that some monuments rotated clockwise, others counter clockwise. (Base map from the Sidney quadrangle.)

the seismic records of the later earthquake. A field study of the first earthquake was made before the second one occurred and after studying the second one excellent material was at hand for comparing the intensities of the two. Such a com-

parison showed greater property damage, greater rotation of heavy monuments in cemeteries, and more displaced objects after the second quake. In one of the grocery stores in the village of Anna some 300 items were shaken from the shelves by the first earthquake while the second one caused some 1300 items to fall to the floor.

At the epicenter, the earthquake of March 2 had an intensity of IV+ and the one of March 9, VI+ as measured by the Rossi-Forel Scale.

LOCATION OF EPICENTER

Various lines of evidence have been used for recording data concerning earthquakes when recording instruments are not available. These criteria are well summarized in Heck's book on "Earthquakes."[2] He points out that a study of the movement of objects on the earth, damage to buildings, feelings experienced by individuals, etc., must be used if the epicenter is to be delimited as occupying a certain definite area in a region. Two types of evidence were found most useful in this study in western Ohio: (1) the movement of relatively free objects as indicating the direction of wave motion; (2) the damage done to buildings, etc. It was found that the directions of movements of objects were remarkably constant for any locality and when these directions were plotted on a map (Fig. 1) they were found to radiate from a central area. Since earthquake waves reach the epicenter first and are later felt in areas surrounding the epicenter the directions of movements should radiate from the epicenter. Similarly it was found that the damaging effects were greater in the area from which these directional movements radiated.

With the foregoing in mind, some examples of movements and property damage may be examined in detail.

INTENSE DISTURBANCES

The property damage in the village of Anna, Ohio, located in northern Shelby County, was greater than in any other town affected by the earthquakes. Here the three-story brick schoolhouse was so badly damaged that building inspectors condemned it and present plans call for the construction of a new story-and-a-half earthquake-proof structure. None of the walls of the structure fell but the brick walls were severely cracked

[2]N. H. Heck: Earthquakes. Princeton University Press (1936), pp. 52–64.

and showed pronounced bulging after the quake (Plate 1). This damage was present on all walls of the schoolhouse but the northeastern corner showed greater displacement and opening of cracks than any other portion. In the same village the brick Methodist Church and one brick residence were irreparably damaged, while the belfry of the Lutheran Church was shaken down and a large interior masonry arch has been removed and replaced by one of steel construction. Practically all of the brick chimneys in Anna were damaged, being either overthrown or rotated clockwise or counter clockwise at high angles. The upper 10 feet of the 3 foot square brick chimney on top of the Anna school moved eastward 3–4 inches and rotated clockwise. The few chimneys remaining upright in Anna usually lean to the north or east. Many foundations were cracked, the filling in old wells settled, and cistern walls cracked. Within a radius of 5 miles of Anna approximately three-fourths of the chimneys required repair. In this zone of intense disturbance the cost of repairing and replacing all damaged property has been estimated to be as high as $300,000.

The movement of objects in buildings and monuments in cemeteries was more pronounced in Anna and the immediate vicinity than elsewhere. In the following discussions it should be remembered that when an object in a building is displaced it does not mean that it will be displaced in the direction the earthquake wave is moving, but rather in the direction from which the wave came. Thus if an object is said to move east with reference to the support on which it rests it means that the earth tremor moved the support west. If a coin is placed on a book and the book is struck at one end the coin will move towards that end which received the impact.

In one of the groceries in Anna a large counter ($20' \times 3' \times 2'$) and a stove weighing 600 pounds moved westward 1—2 inches and heavy laboratory tables as well as filled bookcases in the Anna school moved from 2 to 4 inches in the same direction. Stoves, refrigerators, and bookcases moved east in some houses, north in others, and south in a few residences. Heavy stone steps in front of the Lutheran Church moved 3 inches to the north.

All objects did not move in the same direction in Anna. Lighter objects, as well as heavy ones, show diversified movements. In the Anna public school each room had a radio loud speaker resting on a small shelf above the blackboards. These

speakers were all moved by the earthquakes, tracing their movement in the dust on the shelves. This movement varied between ¼ and 1 inch, with north and south movements predominating over northwest and southeast movements. In the

TABLE I

ROTATIONAL MOVEMENTS OF MONUMENTS IN CEMETERIES

Locality	Distance and Direction from Anna	Age of Monuments*	Max. Rotation	Per Cent Affected
Wapakoneta	12 mi. N.	New....	0	0
		Old.....	0	0
Botkins (Catholic)	5½ mi. N.	New....	10°	20
		Old.....	15°	40
Botkins (New Cemetery)	4 mi. N.	New	15°	35
Botkins (Old Cemetery)	4 mi. N.	Old	40°	65
Anna	(N. E. corner of village)	Old	60°	95
Anna (Old Lutheran)	1½ mi. S.	Old	30°	95
Swanders	2 mi. S.	New	15°	20
Sidney	8½ mi. S.	New....	0	0
		Old.....	5°	5
McCartyville	4 mi. W.	New....	5°	5
		Old.....	15°	35
Schwaberow	7 mi. W., 3 mi. N.	New....	0	0
		Old.....	10°	15
New Knoxville	7½ mi. W., 7 mi. N.	New....	0	0
		Old.....	5°	5
St. Patricks	6 mi. W., 2 mi. S.	New....	0	0
		Old.....	5°	10
Port Jefferson	4½ mi. S., 4 mi. E.	Old	5°	10
Montra	4 mi. E., 2½ mi. N.	New....	15°	50
		Old.....	45°	90
Jackson Center	6 mi. E., 3 mi. N.	New....	10°	20
		Old.....	20°	35
Uniopolis	14 mi. N., 5 mi. E.	New....	0	0
		Old.....	15°	20
Waynesfield.....	14 mi. N., 10 mi. E.	New....	5°	10
		Old.....	15°	20

*Old monuments refer to those in which the cement between sections is virtually absent. New monuments are those erected recently and with well cemented sections at time of the earthquake.

same building pictures on the east and west walls were tilted so that the tops of the pictures sloped south after the earthquake while pictures on the north and south walls were not tilted. In the immediate environs of Anna practically all the pendulum clocks stopped regardless of the direction they faced.

Sectional monuments in the Anna cemetery showed displacement in the form of rotational movement of one section in relation to another. This rotational movement was either clockwise or counter clockwise. Table 1 shows that the degree of rotation and the number of monuments rotated was greater near Anna than in cemeteries farther away from this village. Several lighter monuments were so severely shaken that they toppled over and fell to the ground.

On the basis of the foregoing descriptions the district of greatest damage and the strongest shocks can be confined to an area of approximately 25 square miles (see Fig. 1). The village of Anna is located toward the southwest part of this elliptical area which will be referred to as the epicenter. It should, however, be remembered that such an area is only approximate and may be larger and extend farther to the northeast and southwest. The scattered farmhouses outside of the village furnished fewer observations and correspondingly less detailed study. It is gratifying to find that the epicenter located by this non-instrument method is in complete agreement with the epicenter as determined by seismic observations. The seismic studies showed the epicenter to be located approximately 90 miles due north of Cincinnati.

LESS INTENSE DISTURBANCES

The disturbances away from the area just delimited as the epicenter were obtained directly by observations of the writers or from questionnaires filled out by the families of the school children of the Anna district. The information so obtained indicates a dying out of the intensity of disturbances as the distance from the epicenter increases. The ranges of intensity have been grouped according to the numbers in the Rossi-Forel Scale and determine the positions of the isoseismic lines around the epicenter (Fig. 1). The amount of rotation of monuments and the number of monuments affected in a cemetery decreases rapidly away from the epicenter. These are tabulated in Table 1. Light objects in buildings were displaced in an irregular area of some 100 square miles around the epicenter. North

or south movements are indicated by shelfware falling to the floor from north or south facing shelves in Botkins, 5 miles north of Anna. Little or no displacement of objects was noted at Wapakoneta, 12 miles north of Anna. A few items on shelves moved north in Sidney, 8 miles south of Anna. In these areas of smaller disturbances some pictures were tilted and a few pendulum clocks, whose pendulums swung toward the epicenter, stopped.

As the distance from Anna increases property damage decreases rapidly and is generally noted only in brick chimneys or slight cracks in the walls of buildings. To avoid long descriptions these damages have been plotted on the map (Fig. 1). On this map it will be noticed that west of Anna chimneys lean east; north of Anna they lean south; at Montra, 6 miles northeast of Anna, they lean south or west; at Port Jefferson, 7 miles southeast of Anna, north or west; and at Swanders, 2½ miles south of Anna, north or east.

Before closing the discussion of the earthquake intensities some interesting sidelights of the earthquakes might be mentioned which include: change of water table as evidenced by renewed activity of springs; increased flow in wells; and conversion of ordinary wells to artesian wells. The 21 artesian wells of New Knoxville (12 miles northwest of Anna) showed increased flow after both quakes. A record kept of one of these wells shows the following variations in head:

Date	*Head*
Prior to 1931 quake	11′0″
After 1931 quake	15′7″
Prior to 1937	11′0″
After March 2, 1937, quake	15′4″
After March 9, 1937, quake	18′2″

A gas well, 19 miles east of Anna, drilled into the Trenton in December, 1936, showed a pressure of 175–200 lbs. before the first quake (March 2). After this quake the pressure was reduced to 30 lbs. and subsequent redrilling and shooting has brought no change.

GEOLOGIC CONDITIONS IN THE VICINITY OF THE EPICENTER

No bedrock outcrops are found in the Anna district because of the thick glacial debris which covers the Cedarville dolomite (Niagaran) to an average depth of 100 feet. Occasionally the

distance to bedrock is much greater in pre-glacial valleys which reach the Richmond shales at depths of 500 feet. Ver Steeg[3] has shown several narrow and deep filled valleys in the region, one of which underlies Anna and extends northwest to New Knoxville. Well drillers recognize this quarter mile wide belt as the "deep drive".

The following factors are suggested as possibly having some bearing on the location of the epicenters in the Anna district.

1. The region has experienced many (many as far as midwestern states are concerned) earthquakes in the past. These former earthquakes are listed below:

June, 1876—Intense.
September, 1889—Slight.
Summer, 1892—Intense.
?—1914—Slight.
October, 1925—Slight.
October, 1930—Moderate.
October, 1931—Slight.
March 2, 1937—Intense.
March 9, 1937—Very Intense.

It is interesting to note that at the time of the 1937 earthquakes the Anna public school carried $50,000 in earthquake insurance, a type of insurance carried by very few in Ohio or adjacent states. Since the earthquakes of March 2 and 9, 1937, several other small tremors have been felt in the Anna district, the last occurring on May 3, 1937.

2. The thickness of glacial drift beneath Anna is very great because of the presence of a pre-glacial, filled valley. When earthquakes occur buildings on loose, unconsolidated material will be more seriously affected than those built on bedrock, provided both are subjected to shocks of the same intensity. In this particular instance, however, the greatest damage is not necessarily confined to the area above the valley fill hence it follows that the damage is dependent on the location of the epicenter rather than to surficial geologic conditions.

3. The position of the epicenter may have some relation to the Cincinnati anticline but because structural studies are hampered by the thick covering of glacial drift such a relation cannot be proved or disproved. There is some faulting of considerable magnitude to the north in Wood County[4] but no faults have been found in close proximity to the epicenter.

[3]Karl Ver Steeg: The Buried Topography of Western Ohio, Jour. Geol., Vol. 44 (1936), pp. 918–939.

[4]J. E. Carman and Wilber Stout: Relationship of Accumulation of Oil to Structure and Porosity in the Lima-Indiana Field, Problems of Petroleum Geology, Am. Assoc. Pet. Geol. (1934), (Sidney Powers memorial volume), pp. 521–529.

4. The shape of the epicenter is elliptical rather than circular with the long axis trending north-northeast. This might indicate a small linear disturbance.

5. The small size of the epicenter and the rapid decrease in intensity of the shocks away from the epicenter, as shown by the isoseismic lines, suggest that these earthquakes were of the shallow focus (10+ miles deep) rather than deep focus type.

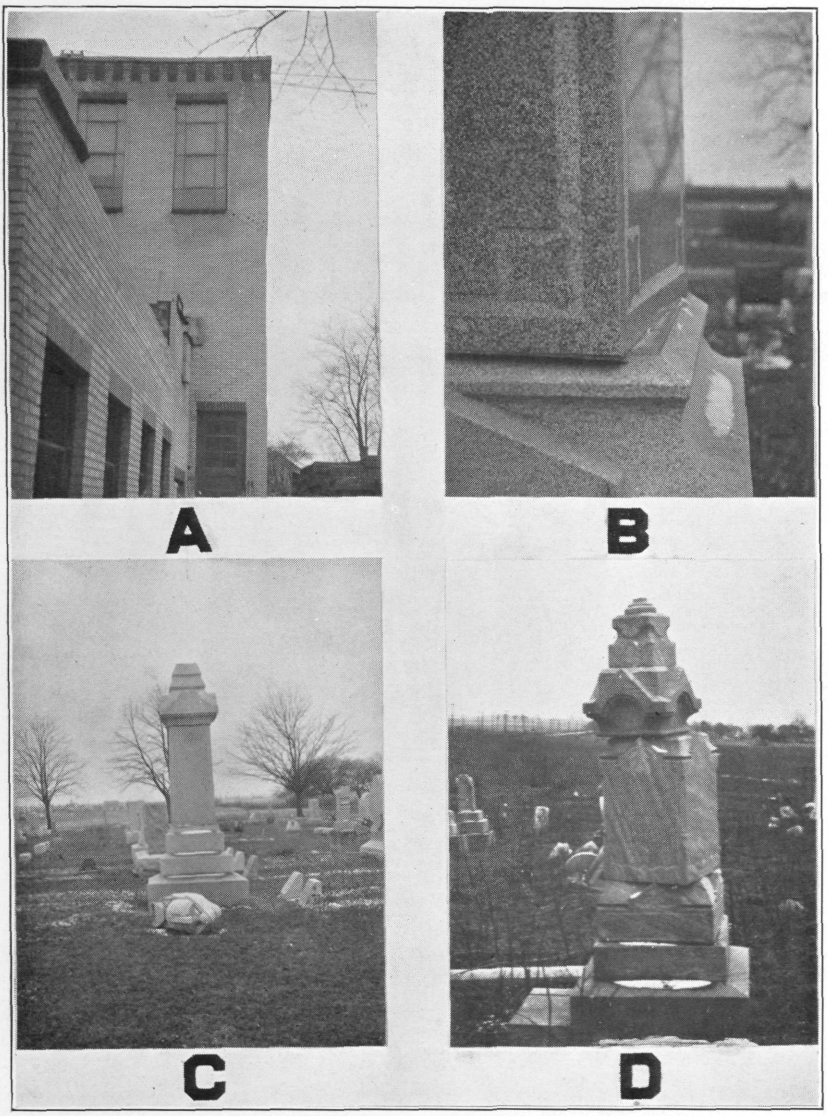
EXPLANATION OF PLATE I

A. Looking west at the northeast corner of the Anna school. Second floor portion of the wall has been displaced to the north as indicated by the cracks in the bricks and the wall pulling away from the window frame.

B. Section of recently erected monument, estimated to weigh two tons, rotated 1½ inches by the quake of March 9.

C. Ornamental urn shaken to the ground from the top of a monument in the Swanders Cemetery by the earthquake of March 9.

D. Rotational displacement of an old monument in the old Lutheran Cemetery, 1½ miles south of Anna, by the earthquake of March 2.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